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Subject: Final Technical Report
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Enclosed is the final technical report for the referenced grant with the required number of copies as outlined in the original award document.

Thank you.

Sincerely,

Judy Keplinger
Contracts & Grants Assistant

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High Precision Frequent Tracking of Drifters Using Commercially Available Global Positioning System (GPS) Components

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13. ABSTRACT (Maximum 200 words)

An instrumentation system has been developed that can provide high-resolution measurements of surface parcel displacement and dispersion in the coastal zone. The design consists of a land-based Differential Global Positioning System (DGPS) reference station and a set of DGPS surface drifters. Drifter position is determined with an accuracy of better than +/- 5m at a maximum sampling rate of ten seconds. Sea surface temperature measurements with an accuracy +/- 0.01C are sampled at the same rate as position. The drifters store data internally and a bi-directional UHF telemetry link allows a limited amount of real-time data transfer. The base station includes the capability of tracking drifters in real-time. The operating range of the current design is 6km from the base station. The drifters have a deployment life of several days. This system can be rapidly deployed anywhere in the world.

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Goal of the Project

The goal of this project is to develop a suite of instruments able to quantitatively measure surface parcel displacement and dispersion in the coastal zone with an accuracy of 1.5 to 2 orders of magnitude better than those obtained using Argos or single-station GPS.

Objectives

The specific objective of this work is to instrument a low cost surface drifter of proven design having minimal windage, with tracking capability able to generate descriptions of surface parcel trajectories over distances of tens of kilometers and times of several days with individual drifter positions reported every few seconds with an absolute accuracy of a few meters relative to a fixed ground-based station.

Introduction

Various methods have been used for tracking drifters in the coastal zone. Among these the Argos location and data collection system has been used most extensively. Single station GPS is a relatively new entrant. Neither provides the resolution necessary for small-scale studies in the coastal zone. The following introduction describes the various systems with emphasis on their limitations. The section concludes with a brief discussion of DGPS, the technology selected for use on this project.

Argos

Drifters with Argos electronics have been seen in use for over a decade. Argos receivers are carried aboard a pair of National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites. Drifter positions are calculated from measurements of the Doppler shift of the transmitter frequency and other parameters. Argos provides several positions a day and categorizes position accuracy in one of three classes: class 1 (1000m), class 2 (350m), and class 3 (150m). A limited amount of data is transmitted to the satellites during each satellite pass. The data and positions are available to the user within a few hours through Global Processing Centers.

We have several years experience using drifters with Argos transmitters deployed in the Santa Barbara Channel off the coast of California (34° N). In the mid-latitudes the satellites pass overhead about 12 times per day. On average, five new locations are computed per day. The accuracy of these locations is most often Argos class 1 or 2.

Single-Station GPS

GPS is a satellite-based radio-navigation system developed by the United States Department of Defense (DOD), which has only recently been integrated into drifter design. A small receiver picks up transmissions from GPS satellites, which enable the three-dimensional measurement of position, velocity, and time anywhere in the world.

The system has a civilian and military component. The Standard Positioning Service (SPS) is available to all users. It is transmitted on the GPS L1 frequency and is

modulated with a navigation data message and a pseudo-random noise code, known as coarse acquisition code (C/A).

The L1 signals from each satellite are used to determine the GPS receiver's range to the satellite, commonly known as a pseudorange. The receiver's position is determined by the geometric intersection of several simultaneously calculated pseudoranges to different satellites. A minimum of four pseudoranges is required to determine the receiver position. If altitude is known, only three pseudorange measurements are required. SPS has the capability of providing horizontal positioning accuracy within 100m (2 drms, 95% probability) and 300m (99.99 % probability)[1]. Positioning accuracy is also biased by signal propagation delays, and satellite and receiver clock errors.

Single-station GPS is often incorporated with Argos. The coupling of both systems improves on the accuracy and frequency of drifter positioning. Argos provides the vehicle for data transmission. At best this combination can provide positions at a rate of one per hour.

DGPS

Single-station GPS accuracy can be improved through a technique called Differential GPS (DGPS). DGPS overcomes various bias errors and the error introduced by C/A modulation on positioning at a single receiver by determining individual corrections for each satellite pseudorange at a land-based reference station and applying the pseudorange corrections to remote receivers. A real-time communication link between the base station and remote receivers is required for DGPS. Single-fix DGPS accuracy is somewhat better than one order of magnitude over single-station GPS. A DGPS system was used for drifter positioning on this project.

Technical Description

The DGPS system is shown in *Figure 1*. It is comprised of a DGPS Base station and several (typically five) DGPS Drifters. An additional component, the DGPS Rover (not shown in *Figure 1*), is used as an aid in the recovery of drifters at the end of a deployment. Each part of the system is described in detail below.

Drifter

The DGPS Drifters float along with surface currents measuring sea surface temperature and GPS position at ten-second intervals. The drifter bodies were designed to maintain close dimensional similarities with the Davis-CODE drifter (Davis, 1982), and, with a very similar drifter we have been deploying in the Santa Barbara Channel under Minerals Management Service support. A vertical PVC pipe houses the electronics and battery; four vertical nylon sails mounted on fiberglass rods provide drag; and four spherical

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[1] United States Naval Observatory, Automated Data Service, Global Positioning System Information, 941103.2350

floats provide buoyancy. The body is made of three-inch diameter schedule 40 PVC pipe approximately three-feet long. Ballast, in the form of lead shot bags, is placed in the bottom of the pipe; then the battery, the drifter controller electronics with GPS, and lastly the radio modem are inserted. The controller and radio modem are rigidly attached to the lid of the drifter with a mounting bracket. The lid is removable, allowing easy access for data downloading or battery changes. Two antenna rods extend upward from the drifter lid: one for the GPS and one for the radio modem. The thermistor for the temperature circuit is potted into a stainless steel fitting in the drifter lid. Styrofoam floats attached with dacron line at each end of the top sail rods provide floatation. When the drifter is deployed, only the antennas and the upper half of the floats are above the water line. The sail rods and sails can be removed for drifter storage and transportation. *Table 1* below lists the main components of the DGPS drifter.

Table 1: DGPS Drifter - Description of Components

Component	Description
Body	Approximate 3' section of 3" diameter Sch 40 PVC pipe. Removable lid machined from PVC rod includes masts and antennas for radio modem and GPS.
Drogue	4 vinyl-laminated nylon mesh sails (18" x 38.75") mounted on 3/8" fiberglass rods. Drifter is suspended at the surface by four styrofoam floats attached to end of sail rods.
Electronics & Power	Center for Coastal Studies DGPS Drifter Controller and Temperature Circuit (based on Motorola MC68HC705CS microprocessor). Center for Coastal Studies 4 MB Flash Memory Storage Device (based on Motorola MC68HC705CS microprocessor). Motorola® VP Encore 8-channel GPS receiver. Pacific Crest® RFM96S 2-Watt Radio Modem. Custom lithium battery pack (14.4V 42Ah).

Base Station

The command center of the system is the base station. An IBM® PC compatible computer running a custom software package controls the base station. It has the functions of transmitting DGPS corrections, polling drifters, logging drifter data, and displaying drifter positions. The base station components are listed in *Table 2* on the following page.

Table 2: DGPS Base Station - Description of Components

Component	Description
Computer	IBM® PC compatible computer running Microsoft Windows 3.1. For this project a 486-33MHz Laptop computer was used.
GPS	Motorola® VP Encore 8-channel GPS Receiver Evaluation Kit and Active Patch Antenna.
Radio Modem	Pacific Crest RFM96S 2-Watt Radio Modem with Diamond Base Station Antenna F718C2.
Software	Center for Coastal Studies DGPS base station software (BASESTN v2.0).

Rover

The DGPS Rover incorporates some of the attributes of the base station and others of the drifter. It was designed to operate from a boat to facilitate the recovery of drifters at the end of a deployment. The DGPS Rover components are listed below in *Table 3*.

Table 3: DGPS Rover - Description of Components

Component	Description
Computer	IBM® PC compatible computer running Microsoft Windows 3.1.
GPS	Motorola® VP Encore 8-channel GPS Receiver Evaluation Kit and Active Patch Antenna.
Radio Modem	Pacific Crest RFM96S 2-Watt Radio Modem with Diamond Base Station Antenna F718C2.
Software	Center for Coastal Studies DGPS rover software (Rover v1.0).
Power Supply	West Marine Sea Gel Deep Cycle Gel Battery and AC to DC converter

System Operation

The DGPS Drifter system operates in the following manner. The base station calculates DGPS pseudorange corrections and transmits them every five seconds to the drifters via an UHF radio link. The drifters apply the corrections when received and internally record position and temperature data to FLASH memory every ten seconds. The base station has the capability of polling each drifter in sequence for its position. The positions of polled drifters are displayed on a scalable target screen at the base station.

Base Station Setup

The base station is placed at the highest point available with a clear view of the study area. Base station site selection is critical in order to achieve maximum performance from the radio link and the GPS receiver. Radio transmission in the UHF band is

considered line of sight, making the antenna height and placement important factors in determining the operating range of the system.

The position of the base station GPS antenna serves as the reference point for DGPS corrections. The coordinates of the reference point are required for input during initialization of the base station software. They must be surveyed to the accuracy with which the absolute geographical position is required. After set up, the base station GPS receiver is powered up for at least 20 minutes prior to initial use to acquire a current almanac, time, and ephemeris data from the GPS satellites.

All base station functions are controlled through a custom software application called **BASESTN** running under Microsoft Windows (*Figure 2*). It performs the following functions: relaying DGPS pseudorange corrections to the drifters, polling drifters for current position, logging drifter data, and mapping drifter position. At startup, the software prompts the user for the base stations coordinates: latitude, longitude, and height. Once the station coordinates are entered, the software begins an initialization sequence that synchronizes the system to the GPS clock and waits for the GPS to lock on to at least three satellites. After initialization, the system will send DGPS pseudorange corrections every five seconds. If drifter polling is enabled, a position request is sent just after the correction.

Drifter Setup

When the drifter is powered up, it will automatically begin an initialization sequence similar to that performed by the base station that synchronizes the system to the GPS clock and waits for the GPS to lock on to at least three satellites. After initialization the drifter will sample and store sea surface temperature and position data once every ten seconds. The drifters transmit data to the base station only when polled.

Deployment

The DGPS system follows a well-defined protocol that operates on a ten-second cycle during deployment as outlined in *Table 4* on the following page. The protocol governs the transmission and reception of pseudorange corrections, polling, and other data at the both either end of the system. At time 0, the drifters save sea surface temperature and position data. At time 3 and 8, the base station transmits DGPS pseudorange corrections. The corrections are received by each drifter and relayed directly to the onboard GPS.

Table 4: DGPS System Cycle

Clock (sec)	Base Station Operation	Drifter Operation
0		Receive position from GPS. Sample sea-surface temperature. Save position and sea-surface temperature data to FLASH memory. Transmit if poll was received.
1	Receive data from drifter that was polled.	
2		
3	Receive DGPS corrections from GPS. Transmit DGPS corrections to drifters. Send position poll to a specific drifter.	Receive DGPS corrections. Receive position request. Check if requested ID matches: if yes, transmit at next second 0.
4		
5		
6		
7	Receive DGPS corrections from GPS. Transmit DGPS corrections to drifters. Send position poll to a specific drifter.	Receive DGPS corrections. Receive position request. Check if requested ID matches: if yes, transmit at next second 0.
8		
9		

A drifter transmits position and temperature data only when polled by the base station. Polling is a user selectable feature of the base station software and can be enabled for a maximum of 10 drifters. The base station sends a poll request directly following the correction message at time 3 and 8. The poll request will command only one drifter to transmit. The base station polls each drifter twice before moving on to the next drifter in the poll list, repeating the list when it reaches the end. The drifter whose number matches the poll request will transmit at the beginning of the next ten-second cycle.

Recovery

Recovery operations are aided by the use of the DGPS Rover. Rover software plots the recovery vessel's DGPS position and any positions received from polled drifters on a target screen on a laptop computer. This allows the recovery vessel to quickly steam to the last reported position of the drifter.

Testing

During development a range of tests were run to qualify the operating characteristics of the DGPS system. The tests provided data on positioning accuracy, repeatability, intervariability, operating range, and deployment operation.

Static Position

A static position test was used to determine the absolute positioning accuracy of the drifters and to determine if drifter operation was affected when several drifters operated in close proximity to one another. During this test, several drifters were bundled together

on a small cart on the Scripps Pier. The cart was left in one position for 45 minutes. At ten minutes intervals, one drifter was removed from the cart and powered down. *Figure 3* is a plot of the latitude and longitude of the drifter positions during the test. A circle of radius 5m was overlayed on the plot with its center at the median point of all the drifter positions. The results demonstrate the DGPS drifter's ability to provide +/- 5m positioning with several drifters operating in close proximity.

Intervariability and Repeatability

The goals of this test were to determine the intervariability and repeatability of the drifters when moved over the same course. Several drifters were bundled together on a small cart on the Scripps Pier. The cart was moved over a course similar to a square wave. Each straight segment of the square wave was roughly 4m long. Three runs were made following the same course. One drifter did not record position during these tests due to problems with the controller.

Figure 4 shows three plots, one for each run, of the intervariability of simultaneous tracks from three drifters. The results of this test were very promising given that the positioning difference between drifters over the same track was well within ± 5m.

Figure 5 includes three plots, one for each drifter, showing the repeatability of the drifter over the same course. The tracks are not as tightly packed as the intervariability tests but are still within ± 5m. Further testing is necessary to determine what may be contributing to the greater range of deviation in these plots.

Range Test

The line of sight distance generally determines the theoretical operating range of the UHF radio transmissions, which is a function of both the receiving and transmitting antenna heights. The base station was set up at the Hydraulics Lab at Scripps with an antenna height of approximately 175 feet. During deployment the drifter antenna rises about 2 feet above the water line. From a radio horizon chart, the theoretical (line of sight) operating range with this configuration is about 18 miles.

Two tests were performed to determine the operating range of the DGPS system with respect to how far DGPS corrections could be received by the drifters and how far the drifters could be tracked. In the first test, two drifters were placed in the water at one-mile increments in a line out to six miles from the base station. The drifters were left in the water for five minutes at each position. The percentage of corrections received by the drifters varied from 56% to 96% and was not correlated with distance. The base station tracked the drifters over the full range of this test.

In the second test, two drifters were placed in the water at three-mile increments in a line out to 15 miles from the base station. The drifters were left in the water for ten minutes at each position. The system worked well up to six miles. At nine miles very few messages were reaching either end of the system.

The operating range results were much lower than expected. The primary reason is believed to be interference from other user on the band. Improvements could be made by: 1) establishing a dedicated UHF frequency for the radio link, 2) increasing the base station transmitter power, 3) raising the base station antenna height, or 4) redesigning the drifter antenna.

Sea Trials

The objective of the sea trials was to acquire several hour-long data records from several drifters. The tests took place off Mission Beach, California. The base station was set up on the top of a San Diego City Lifeguard tower at the foot of West Mission Bay Drive. The initial position was surveyed using a DGPS system operating on the Coast Guard corrections from Point Loma. Antenna height was approximately 10m above sea level. The drifters were deployed from a small vessel. During the tests the map display on the base station was used to track the drifters and inform the boat of the drifter positions.

During Sea Trial 1 (*Figure 6*) five drifters were deployed in a line perpendicular to shore at approximately 250m intervals about 2.5 km offshore. The drifters were in the water for approximately 1.5 hours. During Sea Trial 2 (*Figure 7*), four drifters were deployed in a line parallel to shore at approximately 250m intervals approximately 2.5 km offshore. The drifters were in the water for approximately two hours.

The sea trials were successful tests of the complete system. Several drifters were tracked using the base station for a period of several hours with only a few minor hitches. The spikes in the drifter tracks, particularly evident in *Figure 6*, are caused by loss of DGPS corrections by the drifters. A software bug in the drifter firmware was causing the drifters to inadequately synchronize to the GPS clock at startup. This has since been identified and fixed. Two of the drifters did not record data due to technical difficulties. The problems turned out to be minor and were a result of improper assembly and startup.

On close inspection the drifter tracks started to wiggle toward the end of Sea Trial 2 (*Figure 7*). Analysis has been done to determine if the wiggles were caused by some variability of the GPS or a natural phenomenon. However, the data set was not long enough to provide conclusive indications as to the source of these wiggles.

Tracking the Future

The capabilities of the DGPS Drifters have been proven in the field. Boosting the base station power from 2W to 30W would result in a dramatic increase in the operating range. Improvements could also be made with further testing of drifter antenna designs. Overall system operation would be improved through the use of a dedicated frequency for radio transmissions. The frequency assigned to this project was one that is shared with several users. The high level of traffic in the band caused some interference problems resulting in data collision and a downgraded level of performance from the system.

List of Figures

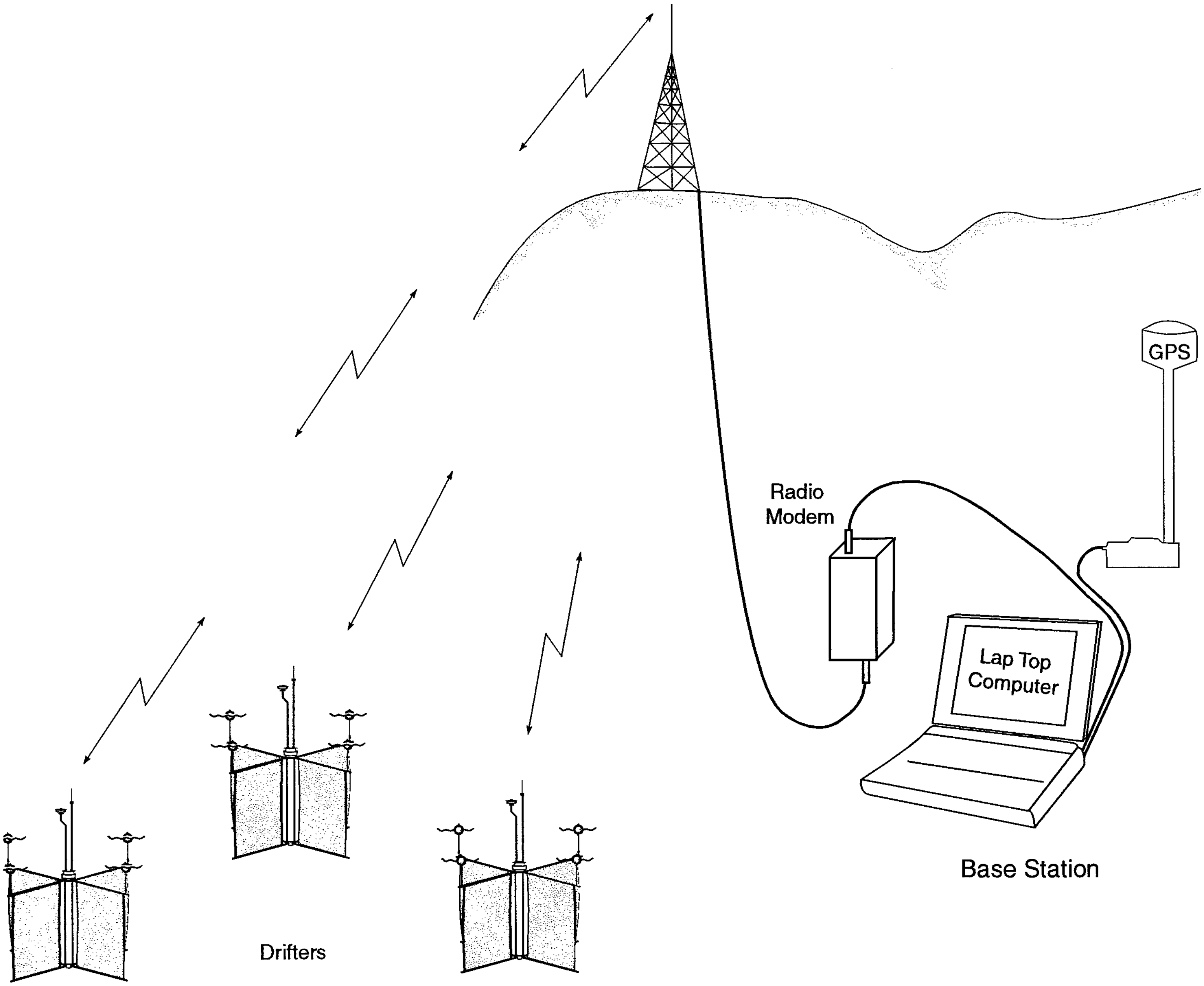


Figure 1: DGPS System Diagram

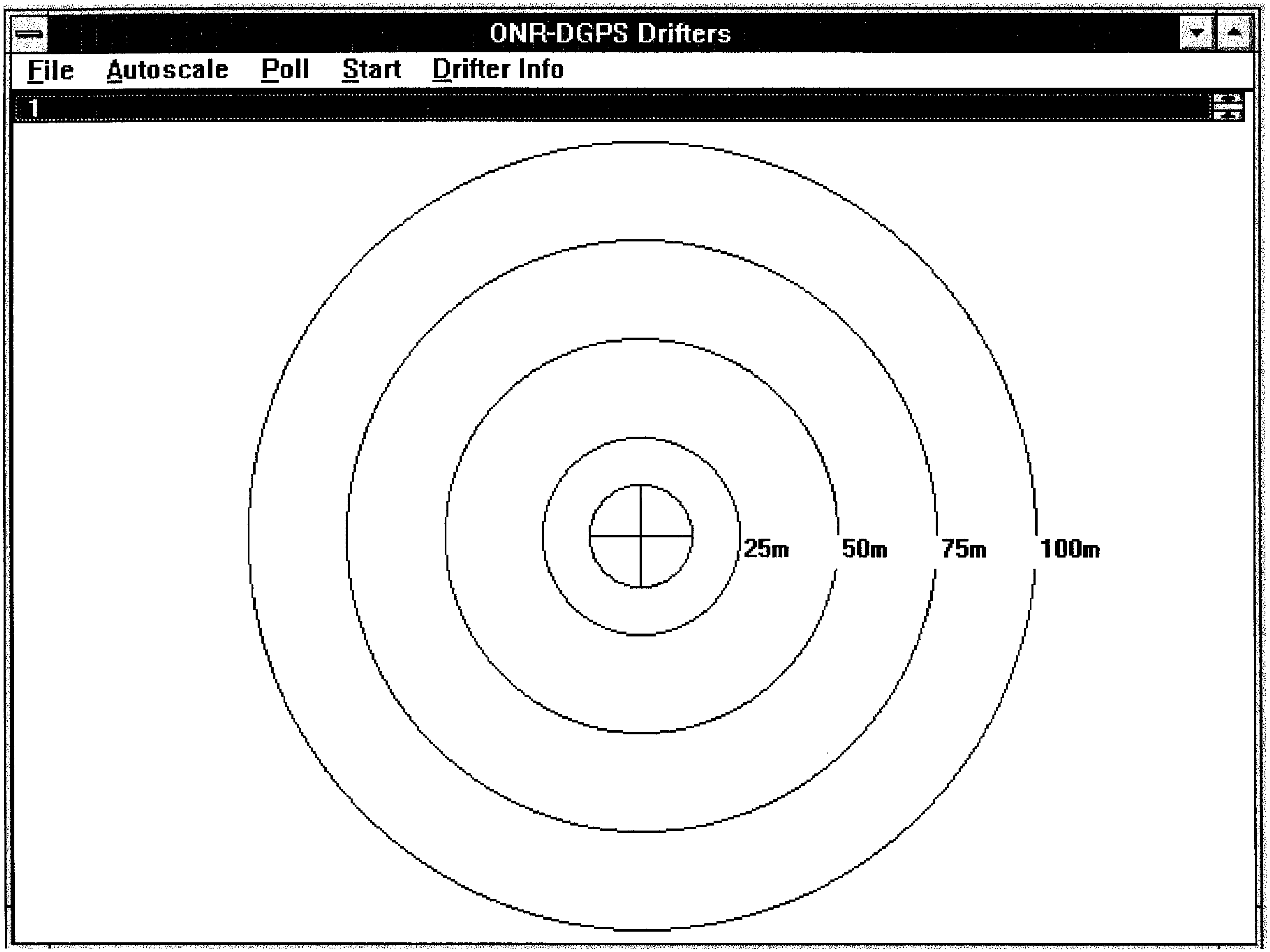


Figure 2: BASESTN 2.0 Screen Shot

Figure 3: Static Position Test

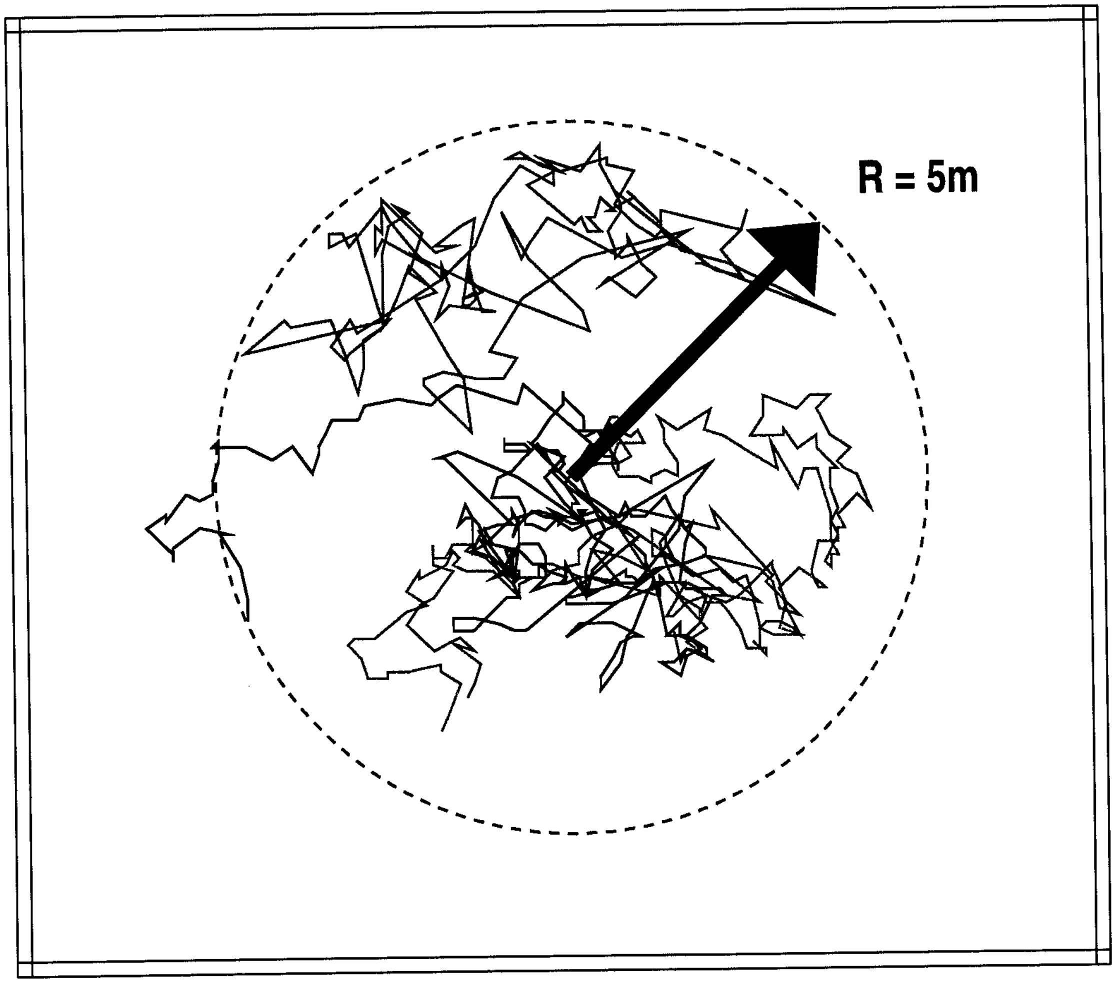
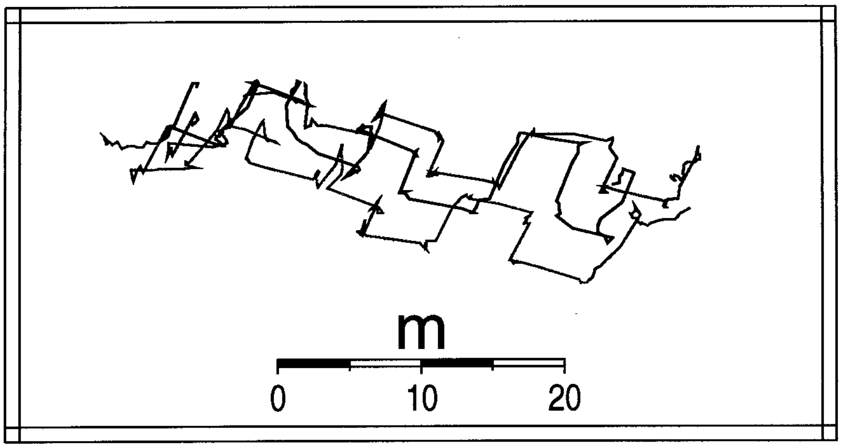


Figure 4: Intervariability

Run 1



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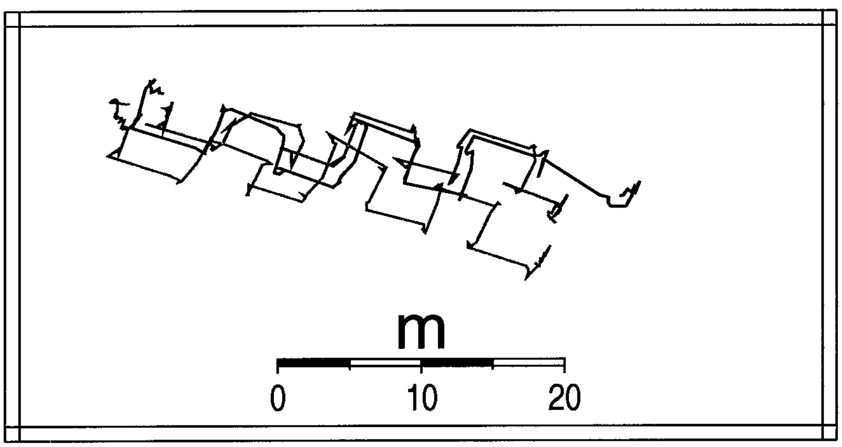

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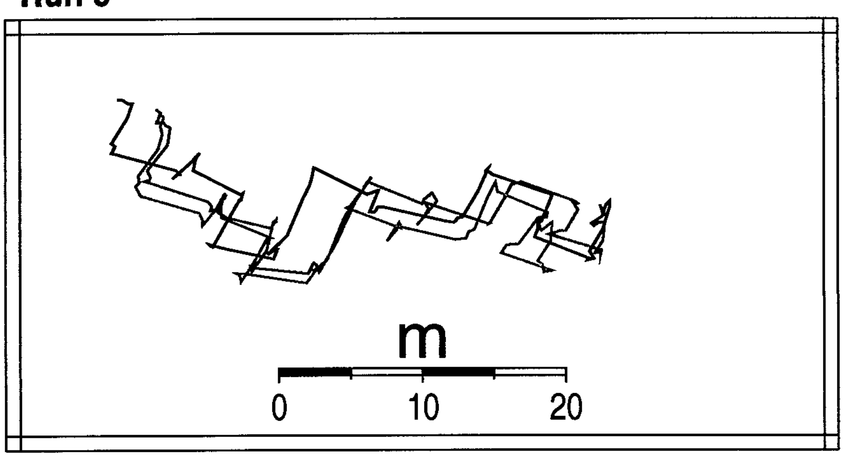
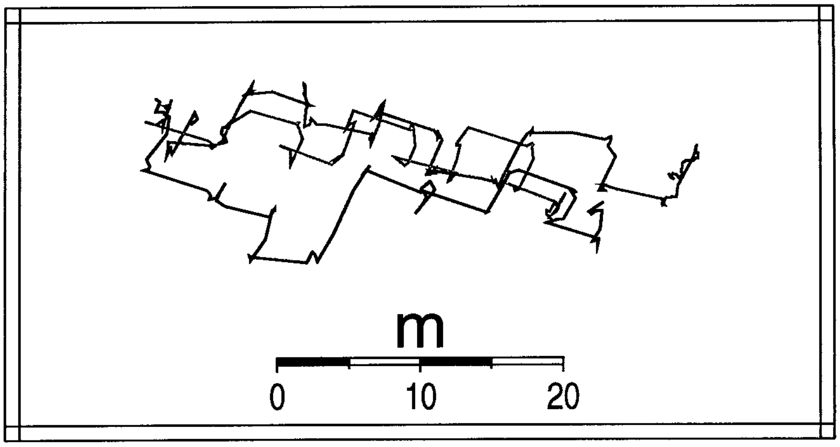
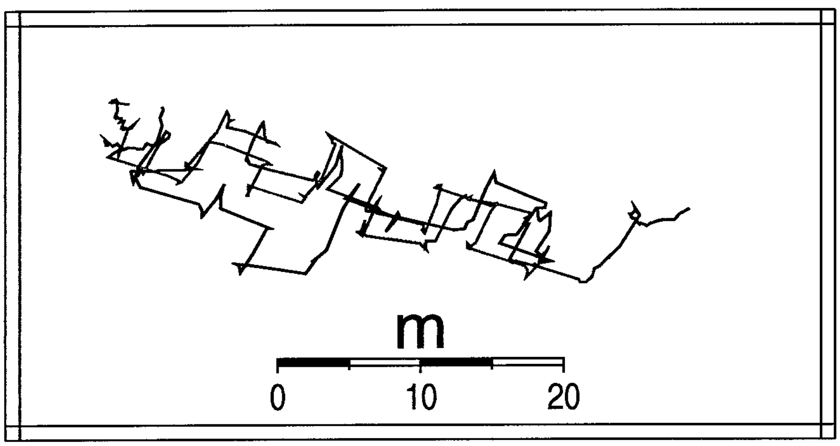


Figure 5: Repeatability

Drifter 3



Drifter 5



Drifter 6

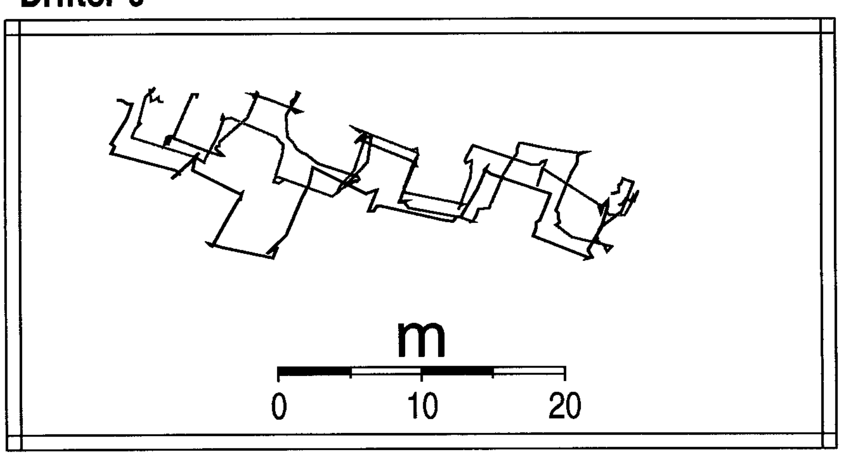


Figure 6: Sea Trial 1

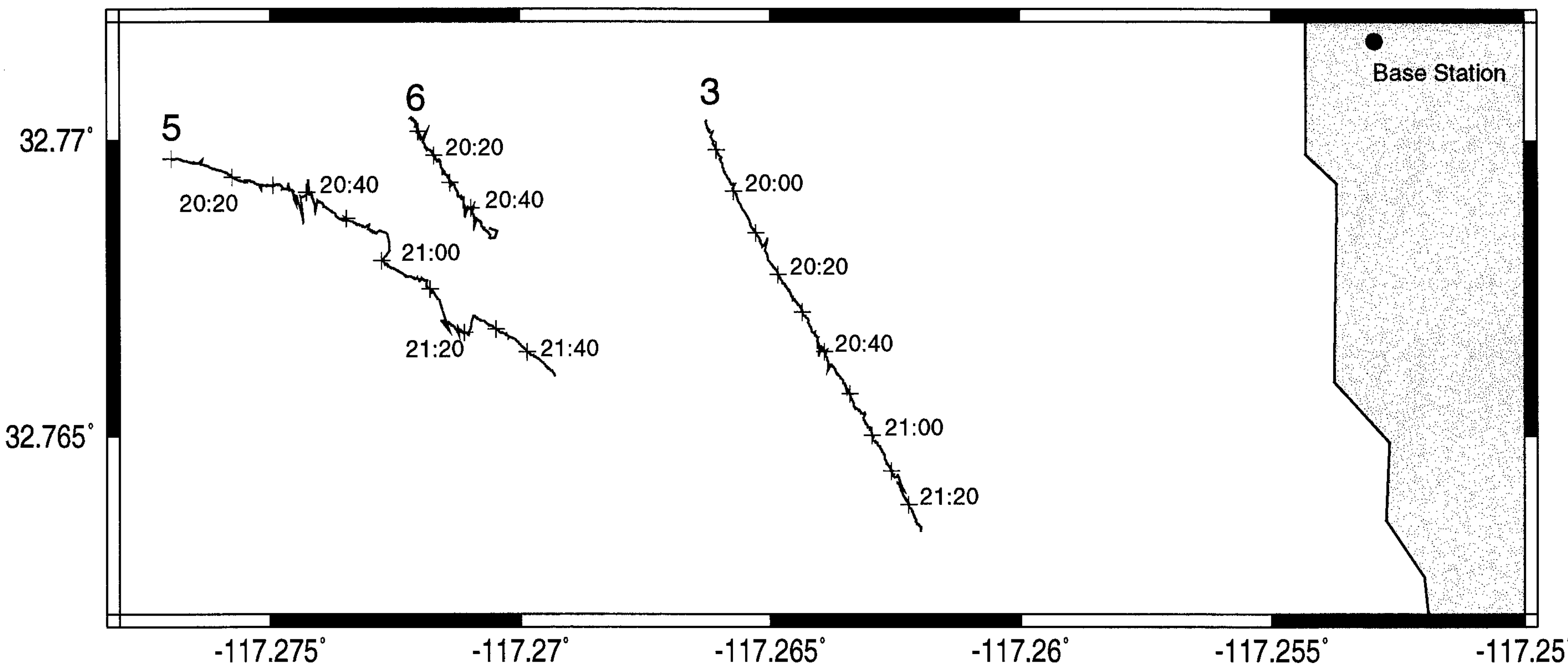


Figure 7: Sea Trial 2